INVESTIGATION OF LASER DYNAMICS, MODULATION AND CONTROL BY MEANS OF INTRA-CAVITY TIME VARYING PERTURBATION

under the direction of

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INTRODUCTION

The work under this Grant will be generally concerned with the generation, control, and stabilization of optical frequency radiation. At present, the projects under this Grant may be divided into two general categories: First are those which are concerned with the control of normally multimode lasers by means of internal time varying perturbation. These projects include an experimental study of FM laser oscillation in ionized argon, a combined theoretical and experimental study of two techniques for obtaining a high power single frequency laser, and a detailed theoretical study of nonlinear AM type mode locking. The projects of the second category are those concerned with the generation of light by means of parametric processes in nonlinear media. These include a combined theoretical and experimental study of optical parametric oscillation wherein the nonlinear element is placed internally to the cavity of the pumping laser; and a second project whose goal is the parametric generation of light without the need for multiple optical cavities. In the following sections we will briefly review the status of each of the above projects.

During this period the following publications have been submitted for publication and are included as Appendices.

S. E. Harris, "Stabilization and Modulation of Laser Oscillators by Internal Time-Varying Perturbation," to be published in the joint issue of the Proc. of IEEE and Applied Optics, October 1966.

S. E. Harris, "Proposed Backward Wave Oscillation in the Infrared," to be published, Applied Physics Letters.

O. P. McDuff and S. E. Harris, "Nonlinear Theory of the Internally Loss Modulated Laser," submitted to the Journal of Quantum Electronics.

The following oral disclosures have also been presented:

L. Osterink, R. Byer, and S. E. Harris, "The Internally Phase-Modulated Laser with Frequency Selective Output Coupling," Quantum Electronics Conference, Phoenix, Arizona, April 1966.

S. E. Harris and M. K. Oshman, "Internal Parametric Oscillation," Conference on Electron Device Research, Pasadena, California, June 1966.

PRESENT STATUS

1. FM Oscillation in the Argon Laser and Single Frequency Techniques

(L. Osterink, L. Byer, and S. E. Harris)

During this period the work on this project has been entirely experimental and has consisted of operating an argon FM laser, studying its quenching properties, and using it to obtain high power in a single frequency. The laser used was dc excited, had a length of 65 cm, and a bore of 2 mm. The internal element was a 5 cm crystal of 45° z-cut KDP, driven at 405 MHz. Experiments performed and conclusions reached during this period were as follows:

(a) It was experimentally demonstrated that an argon laser could be operated in an FM or phase locked manner with only every third cavity mode coupled. This is significant in that the free running laser has all modes oscillating in a highly competitive and nonquenched manner.

(b) In conjunction with R. Targ of the Advanced Technology Laboratories of Sylvania Electronic Systems, an experiment was performed to determine the ability to obtain FM or phase locked operation as a function of power output in the 4880Å and 5145Å argon lines. Successful operation at power levels as high as 300 mw with modulation depths (ω_d/ω_m) between about 4 and 10 were obtained. An attempt was made to operate an argon laser with a driving frequency equal to $4c/2L$. A quenched oscillation could not be obtained in the 4880Å line. In the 5145Å line, successful operation was obtained but showed some instability.

(c) Experiments were performed which demonstrated the method of frequency selective coupling in argon. This technique consists of replacing one of the cavity mirrors with a frequency selective output mirror, i.e., a Fabry-Perot etalon. (See Appendix I for a more thorough description and references.) Using this technique we have obtained a single frequency power of about 50 mw from a laser with a free running power of about 100 mw. However we find that the technique suffers from severe stability problems and will thus probably not be pursued further. The method does appear to be the best suited for a wide inhomogeneously broadened atomic line.

(d) In conjunction with R. Targ of Sylvania, experiments have been pursued on the super-mode technique, wherein the output signal from an FM laser is passed through an external FM modulator and is reconverted to a single frequency. (See Appendix I for further details.) By using an external $LiNbO_3$ modulator, a single frequency output of over 200 mw has been obtained. At this point the efficiency of the process (ratio of single frequency power to total power of the free-running laser) is about 40% and will probably be improved shortly. Earlier work on this project has been supported by the Aeronautical Systems Division of the United States Air Force under Contract AF 33(657)-11144.

2. Nonlinear Theory of the Internally Loss Modulated Laser

(O. P. McDuff and S. E. Harris)

The purpose of this project is to investigate the detailed behavior of a loss modulated laser. The work during this period has been primarily theoretical. Important results obtained include: (a) Determination of the minimum perturbation strength necessary to produce locking as a function of atomic gain and linewidth. (b) A study of maximum pulse amplitudes and minimum pulse width as a function of drive strength. (c) A comparison of AM versus FM type locking.

Detailed results are given in the paper "Nonlinear Theory of the Internally Loss Modulated Laser" which is included as Appendix II.

Earlier work on this project has been supported by the Aeronautical Systems Division of the United States Air Force under Contract AF 33(657)-11144.

3. Parametric Oscillation at Optical Frequencies

(M. K. Oshman, C. Constantinou, and S. E. Harris)

The purpose of this project is to study, both experimentally and theoretically, parametric generation at optical frequencies. Since powerful laser sources are available at only a few discrete optical wavelengths, it is the parametric process which must be relied on to scan the optical spectrum. The basic optical parametric oscillator consists of a strong pumping laser coupled through a nonlinear material to resonant circuits at an idler and signal frequency such that $\nu_s + \nu_i = \nu_p$.

The initial effort on this project is a theoretical study of the dynamics of an optical parametric oscillator wherein the nonlinear material is situated internally to the cavity of the pumping laser. The motivation for this study is two fold: First is the desire to make use of the strong pump fields existing inside the laser cavity. A second more subtle reason is to avoid the power dependent reflections of the pump which are present when a parametric oscillator is driven with an external pumping source.

The principal results thus far obtained in this study are as follows:

(a) Depending on the parameters of the system, an internal parametric oscillator may operate in three distinct modes of operation. First there is the expected steady-state solution wherein the pump limits, and as laser gain is increased the available power is fed into the signal and idler circuits. The second type of steady-state solution is characterized by the fact that the laser gain be greater than the sum of the losses of the signal, idler, and pump. In this solution, increases in laser gain in effect drive the frequencies, rather than the amplitudes of the signal and idler modes. The result is a sharp loss in parametric efficiency. The third type of solution is a periodic relaxation oscillation wherein the pump, signal and idler modes all pulse with repetition rates of about 1-2 microseconds and with pulse widths which are typically about a few tenths of a microsecond.

(b) A study of the question of parametric efficiency has been begun. Results indicate that in many practical cases it will be possible to obtain very nearly the Manley-Rowe limited fraction of the available power of the pumping laser. That is, though it will be difficult to reach threshold, once threshold is reached large tunable power outputs will be obtainable.

In addition to the above analysis, the construction of an experimental setup has been begun. An argon ion laser will be utilized as a pump, with 90° oriented $LiNbO_3$ as the nonlinear element.

4. Backward Wave Oscillation

(C. Someda and S. E. Harris)

We have recently proposed the possibility of a backward wave parametric oscillation in the infrared. In this technique the feedback is provided internally to the nonlinear crystal, and the need for optical cavaties with their attendant difficulties of alignment and stability are therefore avoided. A device which is conveniently tunable over a large portion of the infrared spectrum could result. The details of this proposed technique are given in Appendix III.

At the present time, we expect to have considerable difficulty in obtaining good single crystal selenium. As a result, the experimental work on this project may be detained.

APPENDICES

I S. E. Harris, "Stabilization and Modulation of Laser Oscillators by Internal Time-Varying Perturbation," Microwave Laboratory Report No. 1429.

II O. P. McDuff and S. E. Harris, "Nonlinear Theory of the Internally Loss Modulated Laser," Microwave Laboratory Report No. 1444.

III S. E. Harris, "Proposed Backward Wave Oscillation in the Infrared," Microwave Laboratory Report No. 1442.